Powering the Next Generation of Flight

Technologies To Address Aviation Energy Efficiency and the Environment

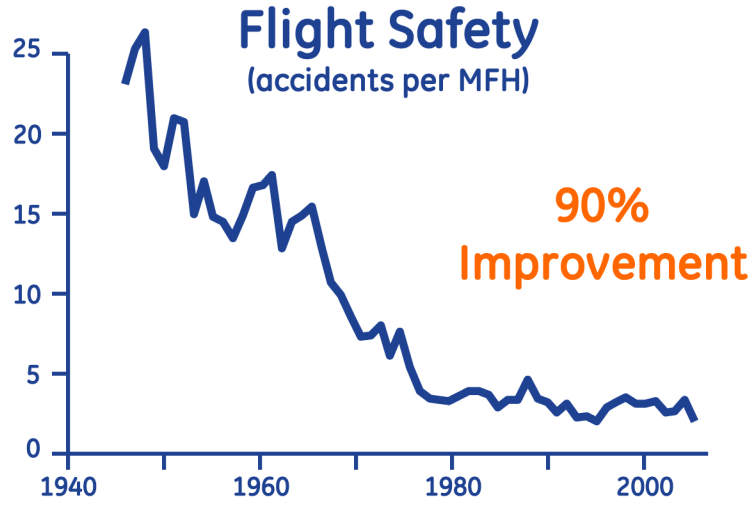
NASA Technology Showcase

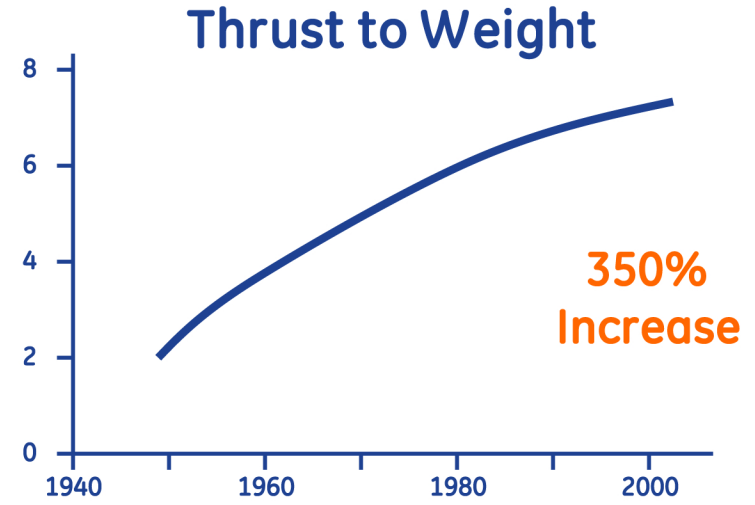
29 November 2012

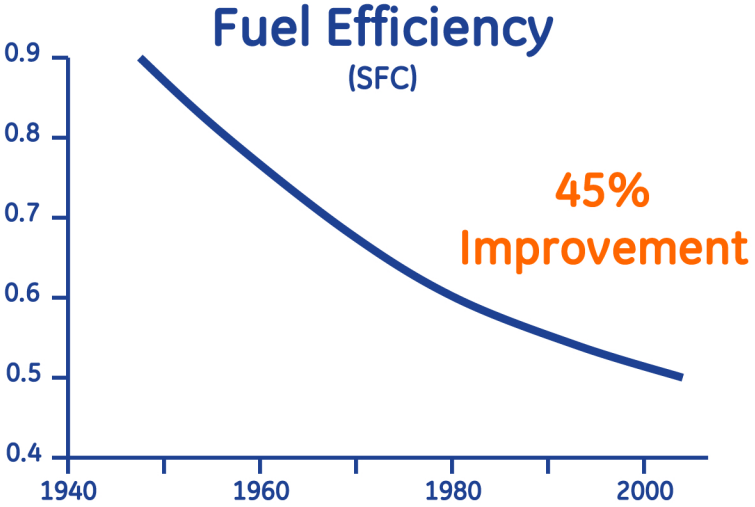
John Kinney
Director, Advanced Technology Business Development
GE Aviation

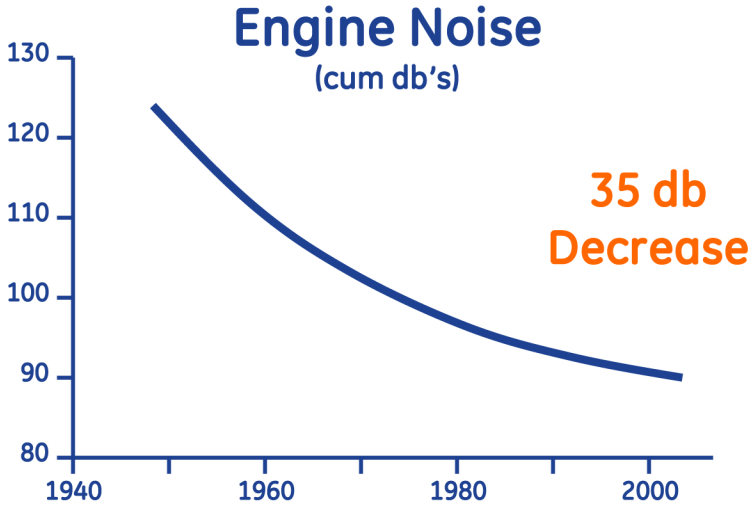
imagination at work

Historical Improvements



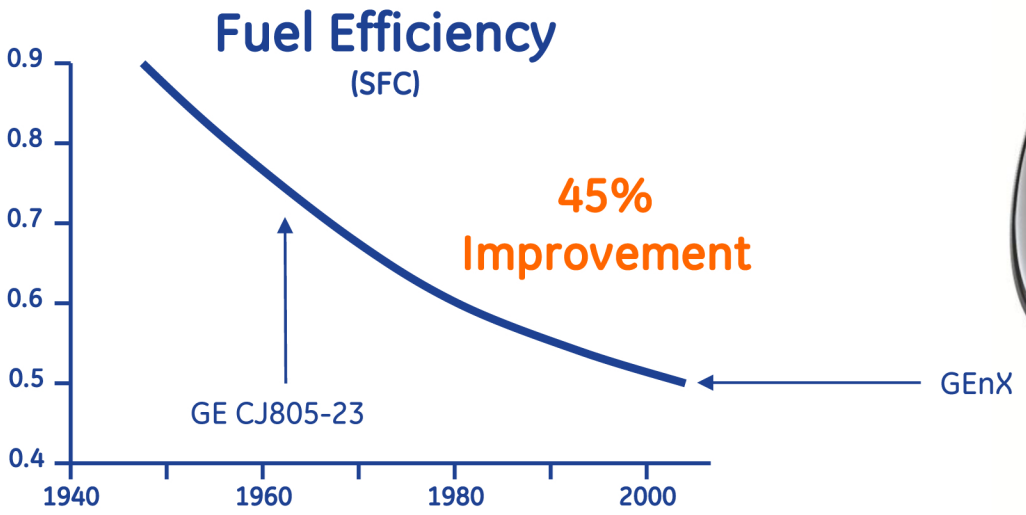


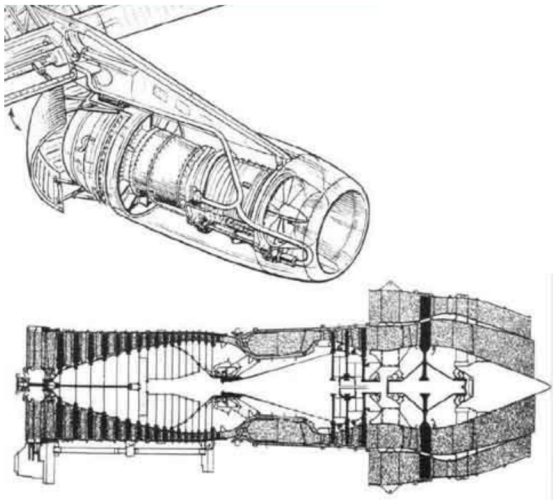


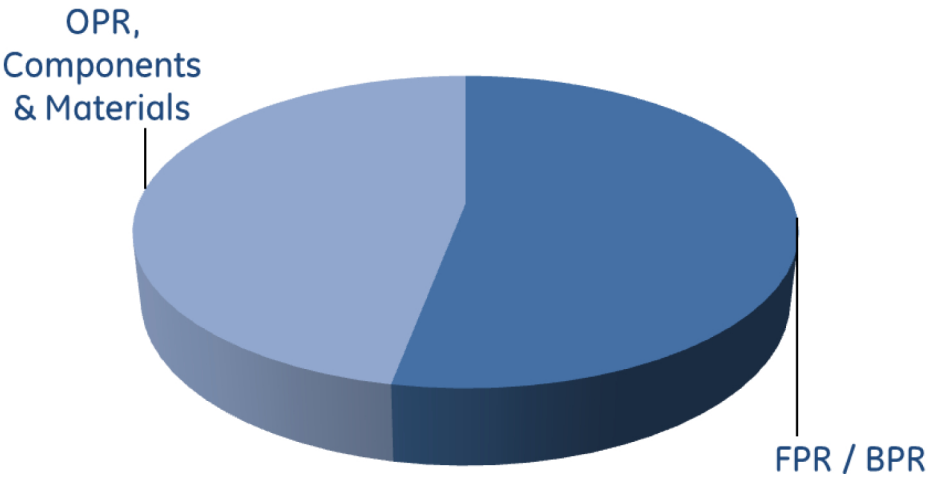


imagination at work

Historical Fuel Burn Improvements



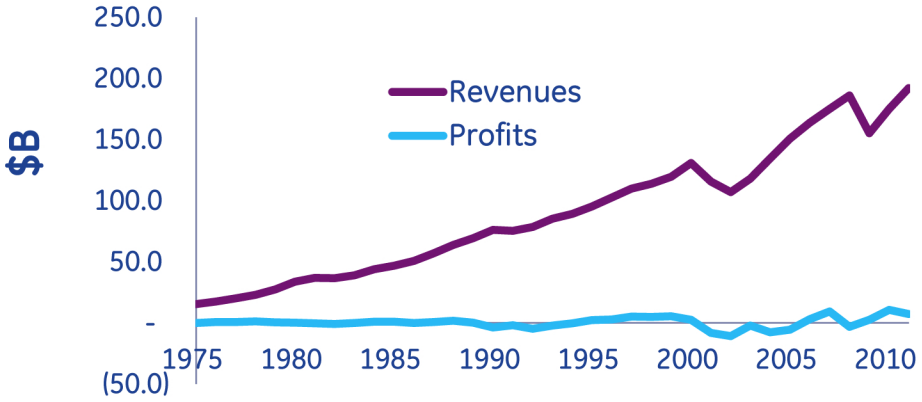




imagination at work

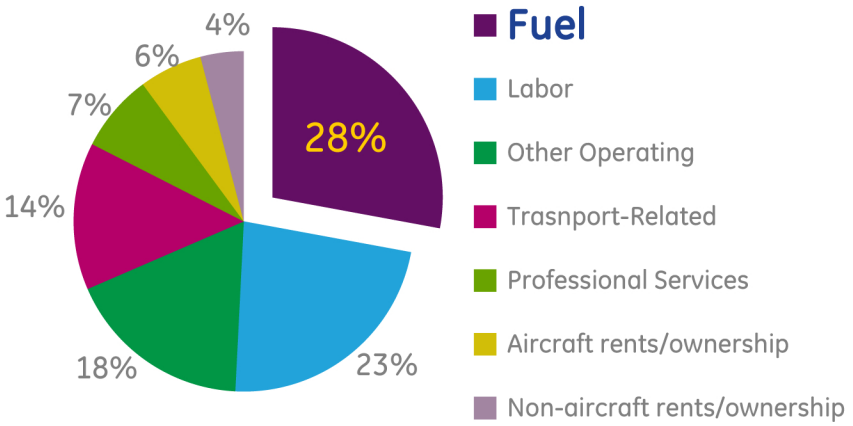
Propulsion Challenge

Industry Revenue/Profits



Sources: Air Transport Association/Bureau of Transportation Statistics

Airline Operating Costs

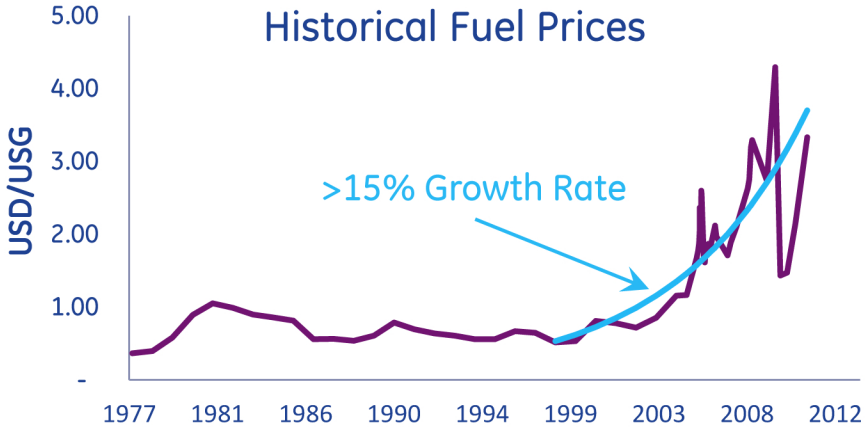


Source: A4A Quarterly Cost Index, US Airlines

Regulatory Challenges

- CAEP/6 — 2008 / 2013
- CAEP/8 — 2014 / 2018
- EU Carbon Trading — 2012
- ICAO CO_2 Standard — TBD

Historical Fuel Prices



Sources: Air Transport Association, International Air Transport Association

Make airlines more profitable in an increasingly difficult environment

The suppliers' broader task …

Delivering customer value with technology - Clean, quiet, affordable and reliable systems

More comprehensive than just lowering GHGs

LOWER

- Fuel consumption
- Emissions
- Noise
- Ownership Cost
- Maintenance
- Disruptions
- Impact of new tech.

Our R&D investments

- Materials
- Aerodynamics
- Combustion
- Cycles / Planforms
- Architectures
- Fuels

Opportunities for the Future

$$Range = \left(\frac{V_0}{SFC}\right) * \left(\frac{L}{D}\right) * \ln\left(\frac{W_{initial}}{W_{final}}\right)$$

$$= \left(FHV * \eta_{thermal} * \eta_{transfer} * \eta_{propulsive}\right) * \left(\frac{L}{D}\right) * \ln\left(1 + \frac{W_{fuel}}{W_{payload} + W_{empty}}\right)$$

	$\eta_{thermal}$	$\eta_{transfer}$	$\eta_{propulsive}$	W_{empty}
N+1	• Highly Loaded Compressors • High OPR Low Emissions Combustors	• Low Loss Inlets • Variable Low Loss Exhausts	• Very High BPR Turbofans	• Novel Alloys / MMC's • Non-metallics
N+2	• Adaptive cycles		• Ultra High BPR Turbofans • Open Rotors	• Advanced Engine Architectures
N+3	• Constant Volume Combustion • Hybrid Electric Propulsion	• Distributed Power Transmission	• Distributed Propulsion • Wake Ingestion	

Composite development timeline

Technology maturation and advancement

Unducted, composite fan blades (UDF)

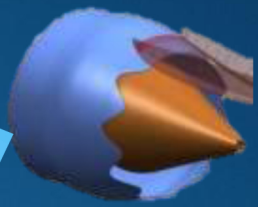
Composite fan blades (GE90)

Composite fan blades *and* case (GEnx)

High temp composites

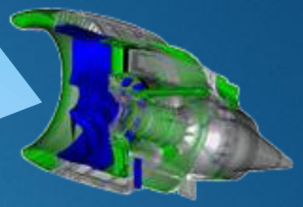
Turbine Blade

Moderate-temp composites



Core Nozzle

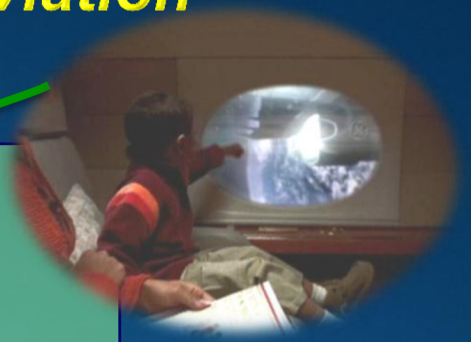
Expanded low-temp composites



80's 90's 00's 10's

Vision for 2030 – 2050 Propulsion Systems

Revolutionary Ideas Required For Future Aviation



Non-Brayton Cycle Propulsion
(CVC, Electric, etc.)

NASA N3-X

Distributed,
Hybrid-Electric

Open Rotor

Brayton Cycle Propulsion
(Turbo Gas Generators)

GE-IA

Key Technologies to Bridge The Gaps

- High OPR Cores
- Advanced Propulsors (Open Rotor, etc.)
- Distributed Propulsion
- Electrical Systems (Fuel Cells, Batteries, Motors)
- Superconductivity / Cryo Systems

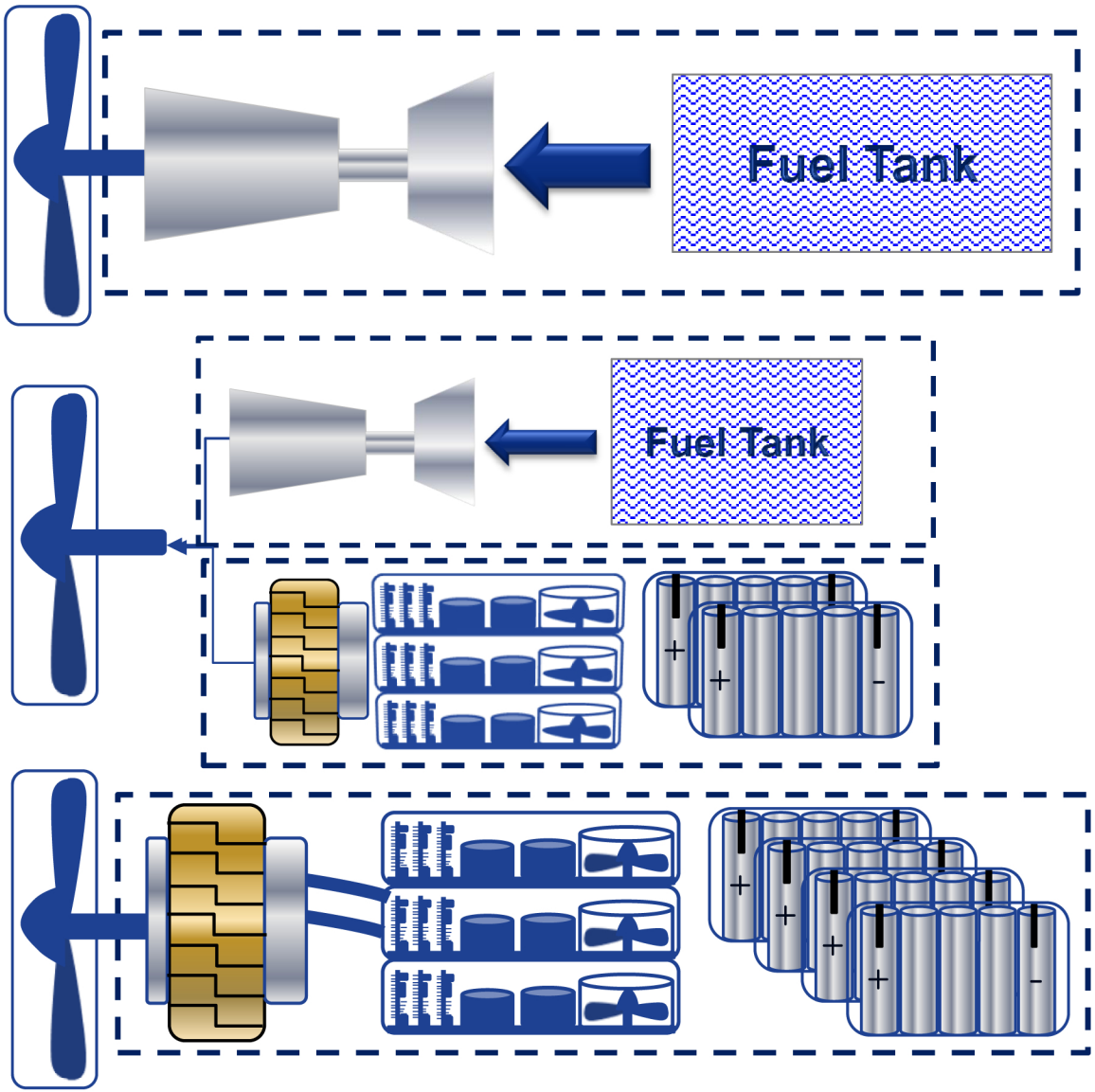
1950

2050

Timeframe

Evolution To All Electric Commercial Propulsion

Revolutionary Technologies Needed



Gas Turbine Engine Propulsion

- Engines ~15,000 lbs
- Fuel ~8,000 lbs
- Total ~ 23,000 lbs

Hybrid Turbo-Electric Propulsion

- Engines ~15,000 lbs
- Fuel ~5,000 lbs
- Motors + Converters~ 2000 lbs
- Batteries ~ 25,000 lbs
- Total ~47,000 lbs

All Electric Propulsion

- Fans + Nacelles ~ 6000 lbs
- Motors + Converters~ 11,000 lbs
- Batteries ~ 55,000 lbs
- Total ~72,000 lbs

Example for Narrow-Body Application

Commercial Electric Propulsion

Coming….But When?

Traditional Hurdles

- "System-Level" benefits/impacts
  - Power/Weight/Volume, packaging
  - Impacts from production, operation and maintenance
- Commercial airframe integration timelines
- Electric Motor Ramp Rate/Impulse
- Prime reliability
- Certification
- Cost

What has changed?

- Increased environmental concerns: noise, emissions, fuel burn
- Fuel costs
- Electrical technology state-of-the-art and projected improvements
  - Batteries and Fuel cell invention

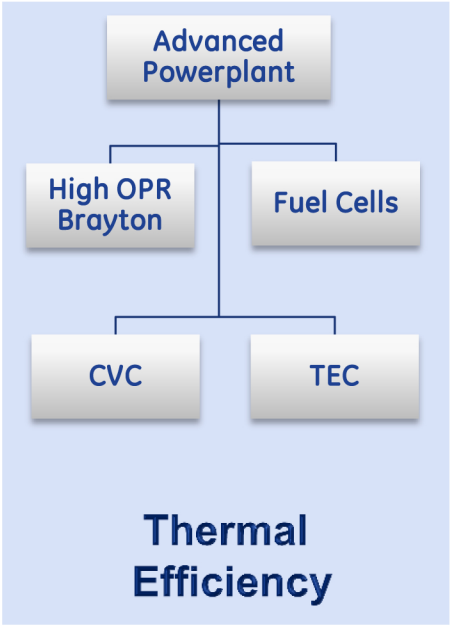
From Published NASA Sites

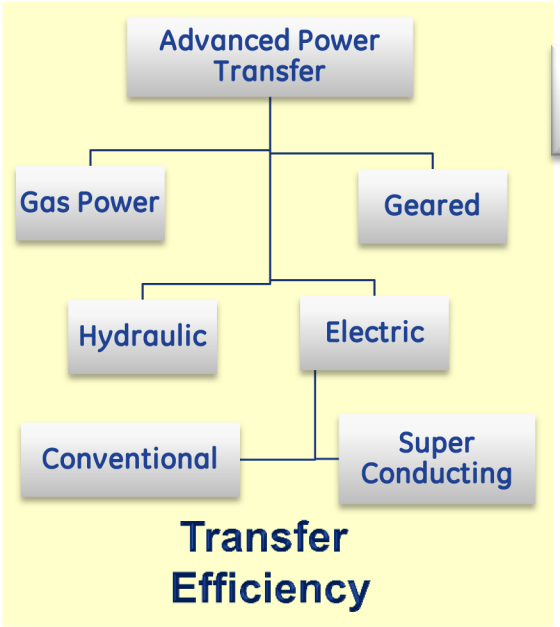
NASA Turbo-Electric Distributed Propulsion Concept

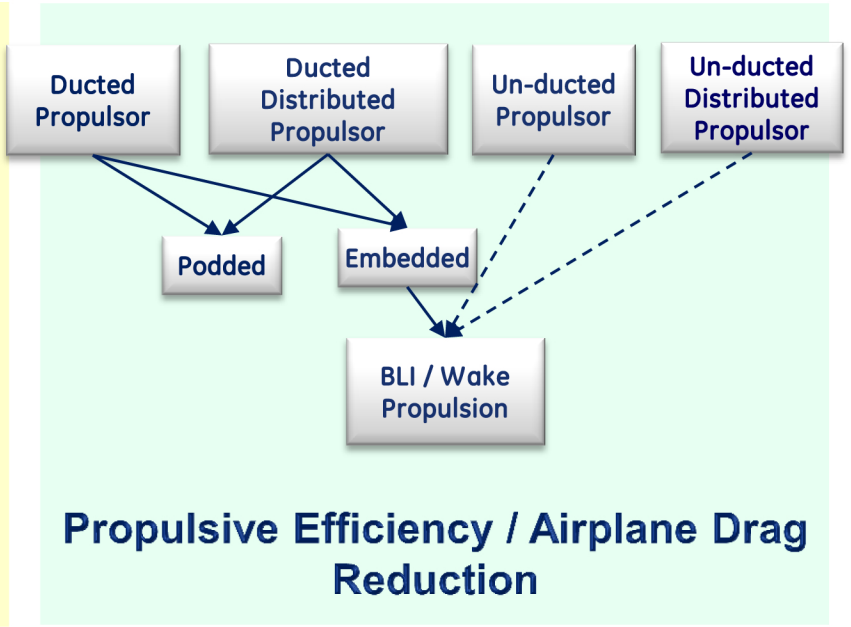
Significant Advancements & Opportunities

Future Engine Design Space

Advanced Airframes







Advanced Power Transfer and Wake Propulsion Enabling Concepts Target Untapped Performance Potential

imagination at work

Key Pacing Items for Future Programs

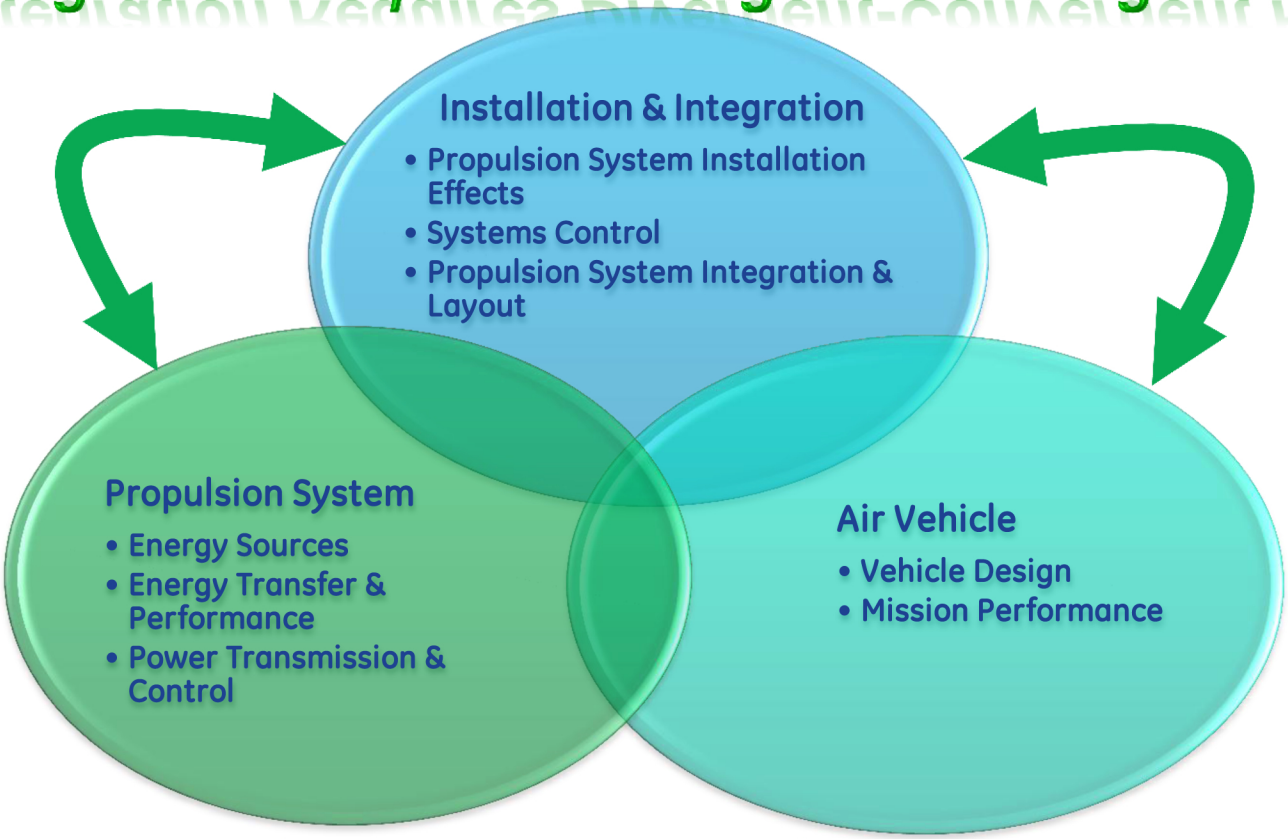
Increased Airframe Integration Needed Sooner in Process

N+1	N+2	N+3 & Beyond
Refining Propulsion		
Non-Metallic Materials	LEAP Program (~2016)	
Distributed Controls		
Advancing Propulsion		
Advanced Metallics & Coatings		TiAl on GEnx ™, Icephobic
Advanced Architectures		Open Rotor, ADVENT
Full Thermal / Power Mgmt and Optimization		INVENT
Flight Path Optimization		4D Trajectory
Revolutionary Propulsion		
Non-Brayton Cycles		CVC, DARPA Vulcan
Hybrid-Electric Propulsion		Fuel Cells, Batteries
Distributed Propulsion		Embedded, Pylon Mounted, Electric

Need Balance of Evolutionary & Revolutionary Technologies

Turbo-electric Distributed Propulsion Design Process

System Integration Requires Divergent-Convergent Process



Systems integration is a divergent-convergent-divergent process

- High level studies assess concept benefits then drive need for detailed studies

Fundamental understanding of advanced technology systems needed

- Systems integration requires understanding of technology trade factors
- Analytic studies and component tests needed to understand system interactions

Safely landing the world's airline fleets

GE's Performance-based Navigation (PBN) Services allow the aircraft to arrive at the airport using precise navigation to ensure optimal efficiency.

GE's TrueCourse℠ Flight Management Systems accurately predict and guide the aircraft to the efficient trajectory in all four dimensions

Summary

Key challenge is minimizing fuel cost while meeting the constraints of the commercial aviation environment:

- **Emissions**
- **Noise**
- **Reliability**

Traditional fuel burn reduction strategies are beginning to yield diminishing returns – innovative technologies are required

- **Light weight / high propulsive efficiency**
- **Highly integrated / distributed propulsion**
- **Non-Brayton cycles**

Multiple paths needed…no "all in" on one innovation!

- **From materials to integrated installations**
- **Near term to 2050+ architectures**

Revolutionary Ideas Required For Future Aviation